Modeling, Performance Analysis and Comparison of Two Level Single Chain Pointer Forwarding Strategy For Location Management in Wireless Mobile Communication.

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Abstract

Global wireless networks enable mobile users to communicate regardless of their locations. Location management is an important part of the emerging wireless and mobile technology. A Personal Communication System (PCS) network must have an efficient way to keep track of the mobile users to deliver services effectively. Global System for Mobile Communication (GSM) is a commonly accepted standard for mobility management of mobile users. Location management involves location tracking, and location information storage. Location management requires mobile users to register at various registration areas whenever they are on the move. The registration process may cause excessive signaling traffic and long service delays. To improve the efficiency of location tracking and avoid call set up delays, several strategies such as local anchor scheme, per-user caching scheme and several pointer

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forwarding schemes have been proposed in the past. In this paper, we propose a new **Two Level Single Chain Pointer Forwarding (TLSCP) Strategy** in which a two level hierarchy of level-1 and level-2 forwarding pointers reduced to single chain length are used. Organizing the pointers in a two level hierarchy and further restricting the pointer chain lengths at both the levels to single chain localizes the network signaling traffic and reduces the call set up delays. To justify the effectiveness of our proposed strategy, we develop an analytical model to evaluate the signaling cost. Our performance analysis shows that the proposed dynamic TLSCP scheme can significantly reduce the network signaling traffic and cost for different categories of users under different network conditions

I.   INTRODUCTION

The phenomenal growth in cellular telephony over the past several years has demonstrated the vitality of mobile communication for users on the move [1]. Infact, in a decade of it's existence, the number of mobile phone owners in Delhi is greater than the number of people who own land line phones. If this is true for a developing country, it maybe safe to assume the same for urban areas of developed countries. One reason for mobile usage gaining popularity is the rapid fall in it's cost. Along with the competition in the electronics industry driving the hardware cost down, improvement in strategies to locate a mobile user and transferring the calls have led to reduction in operational cost. Location management is an important part of the emerging wireless mobile communication system [2]. A network must retain information about location of users in the network in order to route traffic to the correct destination. Location Management has two components:

- Location tracking, and

- Location information storage.

Location tracking mechanisms may be perceived as updating and querying a location database of users to determine when and how a change in location database entry should

be initiated. Location information storage mechanisms help in organizing and maintaining the location database. Location tracking typically consists of two operations:

- (i) updating (or Registration), the process by which a mobile user initiates a change in the location database according to its new location, and

- (ii) Finding (or Paging), the process by which the network initiates a query for a mobile user location (which may also result in an update to the location database).

Two popular and very similar schemes for mobility management are EIA/TIA Interim Standard IS-41 [3] and GSM Mobile application Part (MAP) [4, 5]. However both these schemes use a two tier system of a Home Location Register (HLR) and a Visitor Location Register (VLR) databases and share the same location update procedure. The service area is divided into several registration areas. When a user subscribes to the service, a record or a profile of the user is kept in the HLR, a register located close to the Mobile Switching Center (MSC). When the mobile host moves to a new location or out of the coverage of this MSC, it informs the VLR in the new area and a temporary record is created in the VLR. The VLR sends a registration message to the HLR, which in turn responds with necessary user information. When a call arrives for the mobile user, HLR is queried which in turn submits a query to the current VLR for the current rout-able address of the mobile host. According to these strategies [4, 5], a mobile user performs location update (registration) at the HLR every time the user crosses the boundary of a Registration area (RA) and De-registers at the previous VLR. Thus, the registration process incurs high signaling traffic when many users cross their RAs. This problem worsens with increase in the number of users and when many users are far away from their HLR. To overcome this problem, location tracking techniques should use a combination of updating and finding in an effort to select the best trade-off between update overhead and delay incurred in finding the host. A trade-off also needs to be analyzed between the update and paging costs [6]. The network signaling traffic is also dependent on the geographical location of the HLR databases as it affects both latency and overhead when location information is processed [1]. Both of these factors need to be minimized as they affect the network performance. Distributed HLRs in several areas can

prevent the HLR from becoming a bottleneck in signaling network. The latency can be reduced by using replicated databases where location information is kept at several places in the network. Such user profile replication can reduce HLR access. The amount of signaling traffic may increase slightly as a change in location information after a move must be initiated in all to modify all replications. Various location management strategies for reducing the location management cost have been proposed in the last decade [7]-[15]. The different proposed strategies have been analyzed using different mathematical and analytical models [16]-[18]. Different mobility models [16] have been taken into account to evaluate the performance of these schemes. In random mobility models, a mobile user is likely to move to any one of the neighboring cells, where as, in the activity based models the various activities of the users for classification are taken into account to decide the updating process. Simple Markov models have been utilized to assess and compare the performance characteristics of the 'Degradable location management scheme' [18] using the IS-41 protocol, the Forwarding and Resetting algorithm [11], the Paging and Location Update Algorithm [16] and the Local Anchor Scheme [12]. The proposed 'Local Anchor (LA) scheme' [12] and 'Per user pointer forwarding scheme' [16] avoid expensive HLR updates and access each time a mobile user moves to a new registration area (RA). However, the LA scheme [12] has the drawback of increased local signaling traffic whereas the Per-user pointer forwarding [16] scheme suffers a long set-up delay for highly mobile users. An efficient 'Two Level Pointer Forwarding (TLPF) Strategy' was proposed by Ma and Fang [15], in which a two level mobility management was introduced by selecting a set of VLRs as Mobility Agents responsible for location management in geographically larger area compared to the RA of the VLR. Two kinds of pointers were used between the VLRs and MAs. Registration signaling traffic was localized and thus the network signaling traffic was considerably reduced. The performance analysis of TLPF strategy showed significant reduction in the network signaling traffic for users with low Call to mobility (CMR) with slight increase in the call set-up delay. To overcome the network signaling and call setup delay problems, we proposed a 'Two Level Single Chain Pointer Forwarding (TLSCP) strategy' [19, 20].

Similar to the TLPF strategy of Ma [15], in the presently proposed TLSCP strategy, a two level hierarchy of level-1 and level-2 forwarding pointers has been used. However, in the proposed strategy, the pointer chain length of both level-1 and level-2 pointers chains has always been adjusted and reduced to single chain. Organizing the pointers in a two level hierarchy and further restricting the pointer chain lengths at both levels to single chain reduces the network signaling traffic and call set-up delays. We have further combined the concept of two level single chain hierarchy with choice of replicated HLRs distributed throughout the geographic region. The use of forwarding pointers makes the concept of distributed HLRs more attractive and efficient. This makes the proposed-TLSCP Strategy an efficient and attractive scheme for location management of mobiles. In the present paper, we have done the modeling and performance analysis of the TLSCP scheme using an analytic model. We have also made a performance comparison of the proposed scheme with the Basic GSM [4, 5] and the TLPF strategy proposed be Ma and Fang [15]. In the next section, we describe the basic architecture of the distribution of VLRs and HLRs assumed in the proposed TLSCP strategy to facilitate the presentation and analysis of the strategy. Section III gives the pseudo-code of the Basic GSM strategy and the proposed TLSCP strategy. In section IV, we present an analytic model of the performance of the TLSCP strategy. Comparison of the performance of TLSCP strategy has been made with the performance of TLPF strategy [15] as well as the basic GSM scheme and the results have been summarized in section V. Finally in Section VI we present the conclusion and the future scope of our work.

II.   TWO LEVEL SINGLE CHAIN LOCATION POINTER (TLSCP) MANAGEMENT STRATEGY

The proposed TLSCP scheme is based on PCS architecture. The whole geographic area is divided into a number of sub areas. There are a number of registration areas (RAs) in each sub-area. Each RA has a VLR database maintaining the records of all mobile users present in the RA. We have proposed to dedicate one centrally located VLR in each sub-area to act

as Mobility Agent (MA), responsible for location management of all the mobile users present in the RAs lying in the coverage area of that MA. A hexagonal network coverage model [12] for VLRs has been assumed in which Visitor Location Registers (VLRs) are arranged in rings around the centrally located MA. Thus each MA covers an n-layer VLR structure and would be responsible for location management in a large area. We have proposed a replicated and distributed HLR environment throughout the geographic region. Each distributed HLR maintains one record for an authorized mobile Each HLR is located at the site of Public Switching Telephone Network (PSTN). This offers an advantage that when an incoming call is originated from some remote PSTN, the HLR would be queried directly and Global Title Translation (GTT) would not be required because the distributed HLR is near the Signaling Transfer Point (STP) [21].
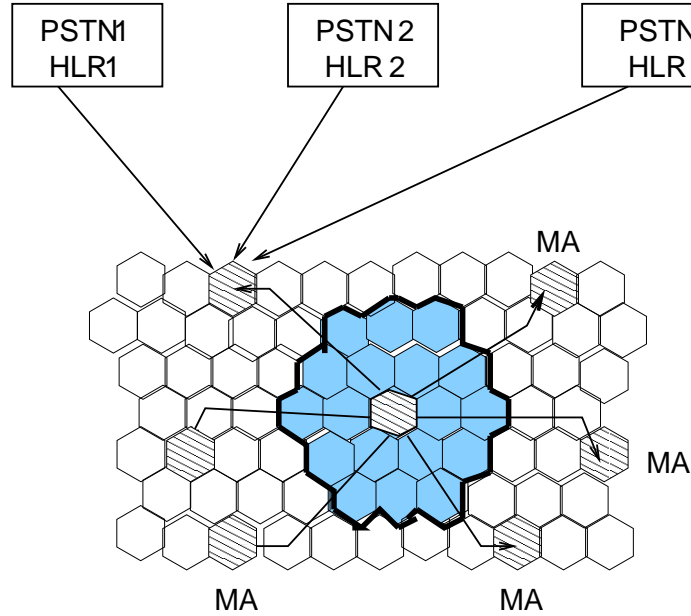

FIG. 1: *A geographical region is divided into numerous hexagonal area called registration area (RA). Various RAs are bought together (example shaded 19 hexas) and a centrally located VLR is assigned the role of mobility agent (MA).*

As mentioned earlier, each distributed HLR has one record for an authorized mobile

user. This record contains the individual MA-id where the mobile was found last time by an individual HLR. Different HLRs may record different MAs/ sub-areas as the head of their own locating paths. So, each HLR may have a different locating path for the same mobile. Thus one cellular system with x distributed HLRs may have y different locating pointer chains (where y≤x) for the same mobile user. Further, as a mobile user moves from one RA to another, a level-2 pointer chain is set up between VLRs of different RAs and further a level-1 pointer chain is set up between MAs if the new RA lies in the coverage area of another MA. The lengths of both level-1 and level-2 pointer chains are adjusted and reduced to single length between MAs and VLRs respectively. This constraint is always true regardless of the HLR from which an incoming call originates. Based on this characteristic, the proposed scheme is called as, 'Two level single chain pointer forwarding strategy' for location tracking in a distributed HLR environment.

III. OPERATIONS DEFINED IN TLSCP SCHEME

The two basic procedures in location management of mobile users are

- Move( )- Defines movement of mobile user from one Registration Area (RA) to another.

- Locate( )- Determines the location of RA where the user is currently located.

The pseudo-code for the two basic operations defined for the GSM and the proposed TLSCP strategy are as follows [19]

GSM MOVE( )

{

The mobile terminal detects that it is in a new registration area;

The mobile terminal sends a registration message to the user's HLR;

The HLR sends a registration cancellation message to the old VLR;

The old VLR sends a cancellation confirmation message to the HLR;

The HLR sends a registration confirmation message to the new VLR;

}

GSM LOCATE( )

{

Call to a PCS user is detected at the local switch;

If the called party is in the same RA, then return;

Switch queries the called party's HLR;

HLR queries the called party's current VLR, V;

VLR, V returns the called party's location to HLR;

HLR returns the location to the calling party;

}

    The pseudo-codes for the TLSCP Move() and Locate() procedures are given below

TLSCP-MOVE( )

{

The user on moving to the new RA registers at the new VLR.

IF NEW-VLR and OLD-VLR both belong to same MA.

{

NEW-VLR deregisters the user OLD-VLR.

OLD- VLR sends Acknowledgement-signal to NEW-VLR.

OLD-VLR sets up a level-2- pointer to NEW-VLR.

OLD-VLR forwards the De-registration signal to other VLRs in level-2 pointer chain.

Length of level-2 pointer Chain is adjusted to single-chain between two VLRs.

}

ELSE

{

User registers at NEW-MA.

NEW-MA sends De-registration message to OLD-MA.

OLD-MA sends Acknowledgement signal to NEW-MA.

OLD-MA sets up a level-1 pointer to NEW-MA.

IF OLD-MA was already a node in level-1 pointer chain.

{

OLD-MA forwards the MA- De-registration message to MAs in level-1 pointer chain;

Level-1 pointer chain length is adjusted to single length between two MAs;

}}}

TLSCP-LOCATE ( )

{

A call to a user is detected at a PSTN switch;

PSTN queries the user's HLR.

HLR queries the MA at the head of its locating chain.

MA queries the VLR pointed by the pointer VLR-PTR in its data entry;

IF VLR-PTR=NULL

{

MA forwards call-request to Next-MA in level-1 MA pointer chain;

}

MA forwards call request to the VLR pointed by VLR-PTR.

VLR locates the user tracking through the level-2 pointer chain.

User's current-VLR sends a rout-able address of user to the MA.

MA forwards the rout-able address of user to HLR and PSTN switch.

PSTN transfers the call to the user.

HLR updates the user's location in its database to current-LN.

}

The detailed protocol of the proposed TLSCP strategy as represented by the pseudo code guarantees that not more than one of each level-1 and level-2 forwarding pointers will be traced to locate a mobile user regardless of the remote PSTN where an incoming call originates. The users have been classified into different classes according to their Call-to-Mobility Ratio (CMR). The CMR of a user is defined as the expected number of calls for a user during the time the user visits an RA, where CMR is defined here in terms of the calls received by the user and not the calls originating from the user. Let

- λ be the mean rate at which calls are received by a user.

- $1/\mu$ be the mean time for which a user resides in a given RA.

Then, CMR represented by 'p'

$$p = \frac{\lambda}{\mu} \tag{1}$$

Assume that the user crosses several RAs between two consecutive calls. If the Basic Strategy is used, the HLR is updated every time the user moves to a new RA. On the other hand if 'Two level single chain pointer forwarding strategy' proposed in the paper is used, the HLR is updated only at the rate at which a user receives calls. So, HLR is updated λ times irrespective of the number of moves made by the user. For all the moves if the calls are not received only level-1 and level-2 pointer chains are set up and their lengths are adjusted. Consider the case in basic mobile telephony, as a mobile user moves he registers himself in the RA he is present in. The RA updates the MA (several RAs are clustered and are ascribed under one MA, shaded region of fig 1.) about the residency of the user. For routing a incoming call to the mobile, the mobile is traced by a pointer pointing between the MA and the RA. Consider fig 2, if the user is in RA labeled V_1, a pointer would exist between MA and V_1. A movement into neighboring RA would result in a new pointer being created between MA and say V_2. This creation of pointer is accompanied by various signal transfers between the MA and RA, creating large signal traffic at MA. To over come this problem Ho et al [12] proposed that a RA acts as a Local Anchor (LA) and any movement within a MA would only result in updating of the LA, thus cutting down the signal traffic to the MA. However, this is at the expense of longer pointers to locate an user. For example if a mobile user goes from V_1 (with V_1 acting as the LA) to V_2 then V_3 (see fig 2), three pointers would exist, namely MA $\rightarrow V_{1-2} \rightarrow V_{2-3}$. While this cuts down the traffic of signals to the MA, in locating a mobile user to connect his call, it would be necessary to traverse the long path MA $\rightarrow V_{1-2} \rightarrow V_{2-3}$. In view of the models advantages Ma *et al* [15] improved upon the model to cut down cost. They achieved their objective by changing the local anchor (LA) after the pointer reached a critical length. The scheme was called "Two Level Pointer Forwarding Strategy (**TLPFS**)".
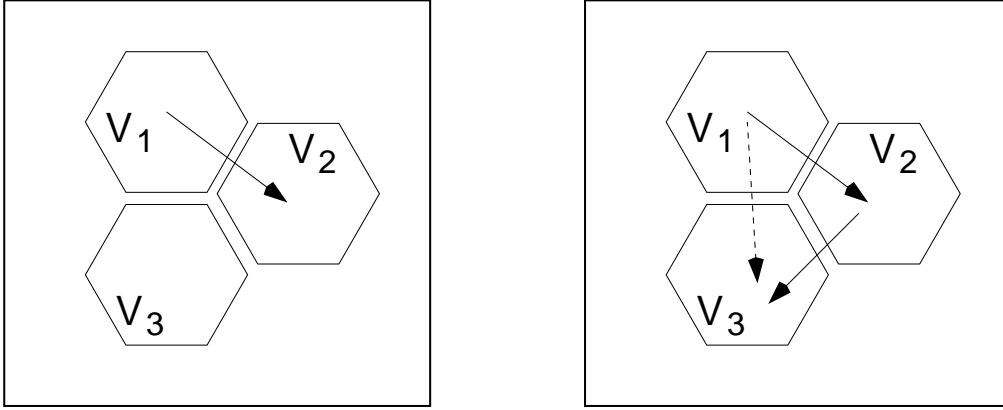
FIG. 2: *Level-2 pointer formation within a MA after one and two steps, respectively.*

In this present model (TLSCP), we propose the formation of a resultant (*as in vector*) pointer with every step to a neighboring RA. This reduces the length of the pointer as also number of pointer to be traversed while locating a mobile to transfer a call (now only two pointers have to be traced). This is at an obvious additional cost of creation of resultant pointers. For example consider the case shown in fig 2. After the first step, the pointer for locating a user would be MA $\rightarrow$ V$_{1-2}$ which after the second step would be updated as MA $\rightarrow$ V$_{1-3}$.

The following section makes the performance analysis of this (TLSCP) strategy. The utility and in-turn the success of this TLSCP strategy can only be estimated by such an analysis.

IV.   PERFORMANCE

In the following section, we analyze the performance of TLSCP strategy for mobile technology along the lines of Ma and Fang's works [15]. At the end, we compare the performance of this strategy with their Two-level pointer forwarding strategy. For this we adopt the same notations of their work with the notations having the same meanings. Adopting these notations as standard would help in performance analysis of all possible

proposed strategies. However, for brevity and easy reference we detail the notations and their respective meanings here,

$\alpha(\text{i})$ = *the probability that there are 'i' VLR crossings between two consecutive calls.*

S_1 = *the cost of setting up a level 1 pointer between two neighboring MAs.*

S_2 = *the cost of setting up a level 2 pointer between two neighboring VLAs.*

A MA is formed by 'n' closely packed hexagonal RA's. As a mobile user moving from one RA to another, in a single step, there is a definite possibility of the user crossing over from one MA to another. While cross-over from one MA to another MA leads to a creation of a new "*level-1 pointer*", cases where such cross-over does not take place, the mobile user is only roaming in one of the various RA's of a given MA. This activity initiates formation of "*level-2 pointers*". The probability of remaining in a given MA after one step movement is given as

$$P_2 = \frac{3n^2 - 5n + 2}{3n^2 - 3n + 1} \tag{2}$$

Thus, the probability of cross-over, and in-turn formation of level-1 pointer, is given as

$$\begin{aligned} P_1 &= 1 - P_2 = 1 - \frac{3n^2 - 5n + 2}{3n^2 - 3n + 1} \\ &= \frac{2n - 1}{3n^2 - 3n + 1} \end{aligned} \tag{3}$$

If the mobile user takes 'i' steps, the number of steps taken within an MA (j) and the number of steps leading to crossing of MA boundaries (k) are

$$j = i \times P_2 = i \left(\frac{3n^2 - 5n + 2}{3n^2 - 3n + 1} \right) \tag{4}$$

and

$$k = i \times P_1 = i \left(\frac{2n - 1}{3n^2 - 3n + 1} \right) \tag{5}$$

respectively. With the knowledge of the probabilities and the total steps taken between two calls, one only needs an idea of the path the user undertakes to calculate the cost due to moving from one RA to another and position movement between MAs. Though such paths would purely be random, one can specify all possible paths and generalize for an estimation of cost. This is what we propose to do in the following section.

A.   Cost due to Move

1.   Cost due to movement within MA

Each *Basic_Move* costs the service provider. The general expression for the cost involved in level-2 pointer formation covers the new VLR visited by the user communicating to the old VLR for informing the users new position. This action is also accompanied by De-registration signal and acknowledgment signal between all the VLRs the user has occupied since the last call. Thus, with each step cost is incurred due to the associated De-registration and acknowledgement. The cost incurred would increase with increasing length of the resultant. Assume a single step movement to the neighboring VLR results in formation of a pointer (vector) whose length is R_1 and represents the cost of pointer formation. For the first step, this would be the resultant itself. To estimate the cost incurred as a user moves, we assigned the cost as S_2 (i.e. the cost incurred on setting pointer R_1 is S_2). When the mobile user takes a second step (see fig 2b) another pointer R_1 is set representing the step taken to neighboring VLR (V_2). As per our scheme, a sequence of signalling results giving rise to single chain pointer R_m. Again the cost incurred in setting up this pointer would be proportional to it's length. The length of the resultant pointer formed would be given as

$$R_m = \sqrt{R_{m-1}^2 + S_2^2 - 2S_2R_{m-1}cos\theta} \tag{6}$$

where θ is the angle enclosed between the pointer of the latest step (R_1) and the previous resultant. In the example of fig 2b, the second step resultant is ($\theta = 60^\circ$)

$$R_2 = \sqrt{R_1^2 + R_1^2 - R_1R_1} = R_1$$

The assumption of hexagonal areas defining a VLR reduces the possibilities of θ to 0° (user steps backward), 60° (user moves in circles), 120° and 180° (moves radially outward). One can generalize the cost involved on taking 'j' steps within a MA by counting all the pointers set up with each step as

$$= (j-1)R_1 + \sum_{m=1}^{j} R_m \tag{7}$$

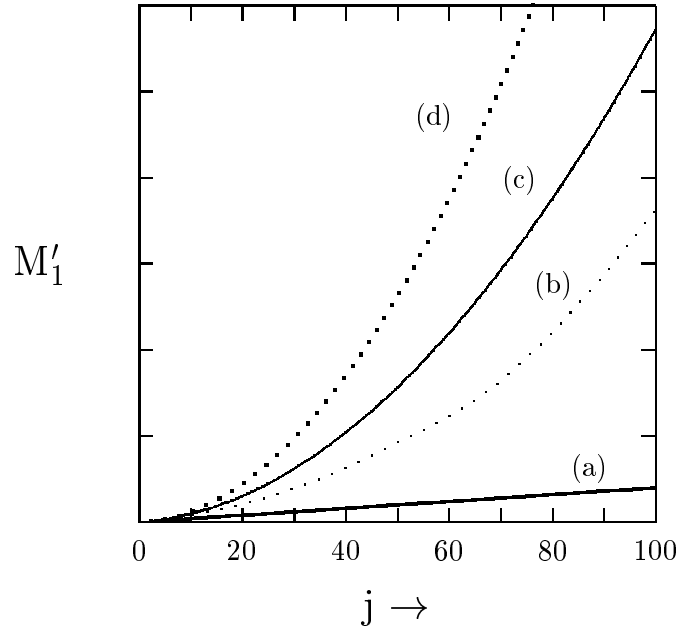Figure 3 shows the cost incurred for various paths taken by the user for increasing number

FIG. 3: *Variation in cost incurred on level 2 pointer with increasing steps taken. The graph is plotted for unity cost, i.e.* $S_2 = 1$. *Curve (a) is when second step is taken at* 60° *w.r.t. previous resultant while (b) shows cost variation for steps taken at random angles w.r.t. previous resultants.*

of steps. The curve showing the cost for circular and radially outward motion encloses all possible paths. Curve (b) shows cost for a randomized motion (user takes random θ with each step. This curve was numerically stimulated). As expected this curve lies between the limiting cases of circular and radially outward motion. Using eqn(6) and eqn(7) it can be seen that the cost involved in setting up level-2 pointer in case a user is moving in circle

around the originating VLR is related to the number of steps taken (j) and is given as

$$= (2j - 1)R_1$$

A similar neat expression is obtained for the user moving radially outward and is given as

$$= (0.5j^2 + 1.5j - 1)R_1$$

Since cost incurred by a random motion would lie between curves represented by these two curves, one can expect a quadratic expression for estimating the cost incurred in pointer formation (level-2) due to any random motion after 'j' steps as

$$= (aj^2 + bj - 1)R_1$$
$$= (ai^2P_2^2 + biP_2 - 1)S_2 \qquad (8)$$

where simple algebra shows that since curve (b) is constraint to lie between curve (a) and (d) the coefficient 'a' can take only values between zero and $1/2$ and the coefficient 'b' should have values between 1.5 and 2 besides satisfying the condition a+b=2. A polynomial of higher order was not selected for simplifying calculations as also to retain some generality of expression.

2. *Cost due to movement outside MA*

As the user moves out of a MA, signals of registration and De-registration are sent between the new VLR and the previously occupied VLR. Recognizing the new VLR to be existing outside it, the original MA sends information to the original HLR. The original HLR sets a level-1 pointer between itself and the HLR associated with the new MA. The level-1 pointer is also setup between the new HLR and new MA. Thus, with every movement outside a MA, two level-1 pointers are set. Thus, k steps outside the MA would result in 2k level-1 pointers being set, which would cost

$$= 2kS_1 \qquad (9)$$

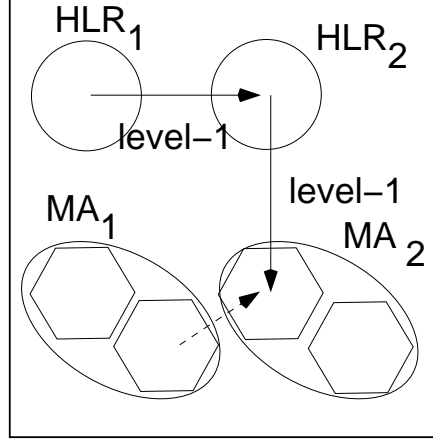where S_1 is the cost involved in setting a level-1 pointer.

FIG. 4: Two level-1 pointers are created when user moves between MAs. Dashed arrow represents level-2 pointer.

3. Net cost due to movement

The net cost incurred on taking 'i' steps with probability of remaining in the same MA being P_2 and that of crossing being P_1 can be written as

$$= (aj^2 + bj - 1)S_2 + 2kS_1$$
$$= (ai^2 P_2^2 + biP_2 - 1)S_2 + 2iP_1 S_1$$

The expected (average) cost would be

$$M' = \sum_0^\infty \left[(ai^2 P_2^2 + biP_2 - 1)S_2 + 2iP_1 S_1 \right] \alpha(i) \tag{10}$$

where α(i) is the probability that 'i' steps would be taken. Simplifying

$$M' = aP_2^2 S_2 \sum_0^\infty i^2 \alpha(i) + (bP_2 S_2 + 2P_1 S_1) \sum_0^\infty i\alpha(i) - S_2 \sum_0^\infty \alpha(i)$$
$$= aP_2^2 S_2 \int_0^\infty i^2 \alpha(i) di + (bP_2 S_2 + 2P_1 S_1) \int_0^\infty i\alpha(i) di - S_2 \int_0^\infty \alpha(i) di \tag{11}$$

To obtain an parametric expression for M', we would have to compute the integrals. The definition of α(i) demands

$$\int_0^\infty \alpha(i) di = 1 \tag{12}$$

$$\int_0^\infty i\alpha(i)di = i_{average} = \frac{\mu}{\lambda} = \frac{1}{p} \tag{13}$$

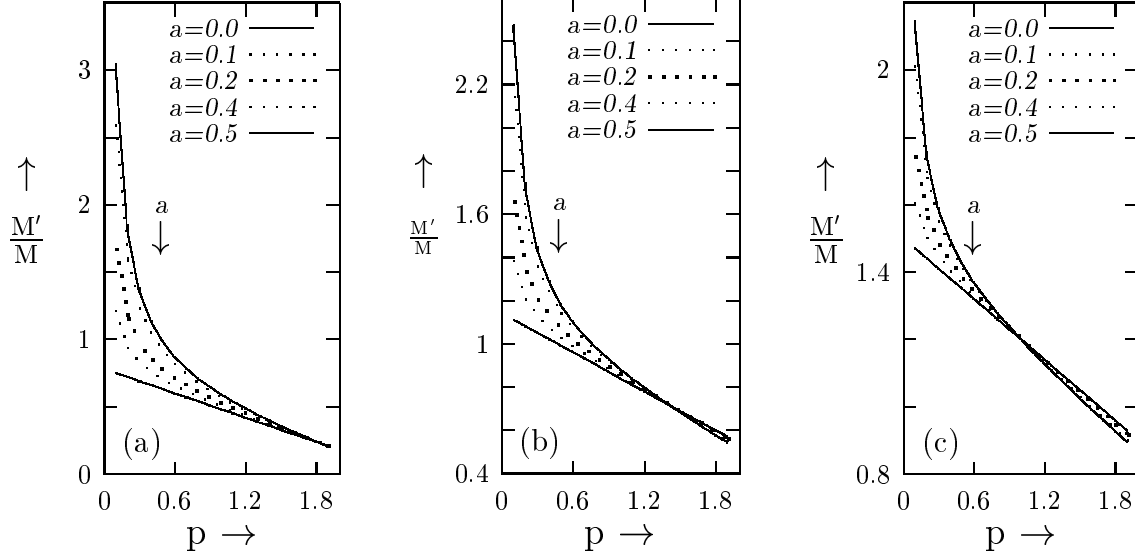where 'p' represents the *Call to Mobility Ratio, CMR.* We have

FIG. 5: *Variation in relative MOVE cost with decreasing probability (a)* $P_2 = 0.9$, *(b)* $P_2 = 0.7$ *and (c)* $P_2 = 0.50$. *The family of curves is shown for varying coefficient 'a' of eqn(8).*

$$\int_0^\infty i^2\alpha(i)di = A\int_0^\infty i^2 g^i di = -log(g) \times -\frac{2}{[log(g)]^3} = \frac{2}{p^2} \tag{14}$$

(detailed derivation is given in the Appendix). On substituting the results of eqn(12), (13) and (14), eqn(11) reduces to

$$M' = \frac{2aP_2^2 S_2}{p^2} + \frac{(bP_2 S_2 + 2P_1 S_1)}{p} - S_2 \tag{15}$$

This is the cost incurred by MOVE (mobility) of the user. Assuming the basic MOVE cost to be unity (i.e. x=1), then

$$M = \frac{x}{p} = \frac{1}{p}$$

Hence, the relative MOVE cost would be given as

$$\frac{M'}{M} = \frac{2aP_2^2 S_2}{p} + (bP_2 S_2 + 2P_1 S_1) - pS_2 \tag{16}$$

Since setting up level-1 pointers is always more costlier then setting up level-2 pointer, $S_1 = \kappa S_2$ where $\kappa > 1$. The relative cost involved in MOVE can now be written as

$$\frac{M'}{M} = \left[\frac{2aP_2^2}{p} + (bP_2 + 2\kappa P_1) - p \right] S_2 \qquad (17)$$

Figure 5 shows the variation in the expected cost on a MOVE action with 'p', the CMR. The figure shows three cases for different values of P_2, the probability of the user moves within the same MA. As expected, the cost is less for the situation where chances of cross-over is less. This is also evident from the slope of the curves. Notice that the curves of each set intersect, however at different values of 'p'. The curves of fig 3 also intersected at j=1 and the point physically represented the mobile user's first step. The physical significance of 'j' is distributed to 'p' via P_2 in our mathematics. Hence, any interpretation of the curves of fig 5 should be from the point of intersection and towards p=0. Decreasing value of 'p' represents increasing steps taken by the user or in other words increasing mobility.
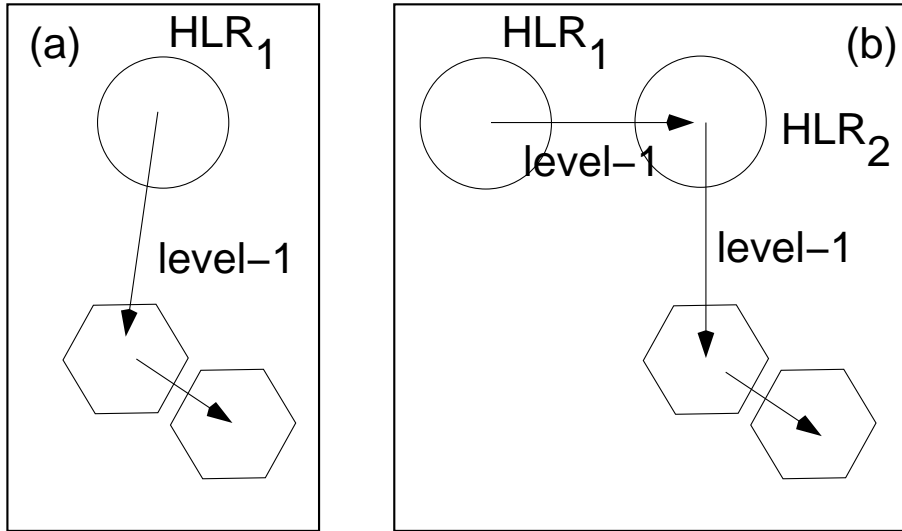
B. Locate

FIG. 6: Two possible methods that pointer would be used for locate (Tracking).

The locate activity of the service provider only takes place when a call is made. Since the level-2 pointer is always being updated to the shortest length (between VLR occupied at time of last call and the latest VLR occupied, irrespective of however many steps were taken), there are only two possible scenarios for locating a user in this model (see fig 6). The average cost incurred in tracing a user would hence be given as

$$F' = F + \sum_{i=0}^{\infty}[iP_2(T_1 + T_2) + iP_1(2T_1 + T_2)]\alpha(i) \tag{18}$$

where 'F' is the basic cost of a trace (we idealize as =1), T_1 the cost of level_1 tracing and T_2 that of level_2 tracing. Simplifying, we have

$$
\begin{aligned}
F' &= F + [P_2(T_1 + T_2) + P_1(2T_1 + T_2)]\int_{i=0}^{\infty} i\alpha(i)di \\
\frac{F'}{F} &= 1 + \frac{[P_2(T_1 + T_2) + P_1(2T_1 + T_2)]}{p}
\end{aligned}
\tag{19}
$$

The cost incurred for locating would be less than S_1 and S_2 since setting up of pointers
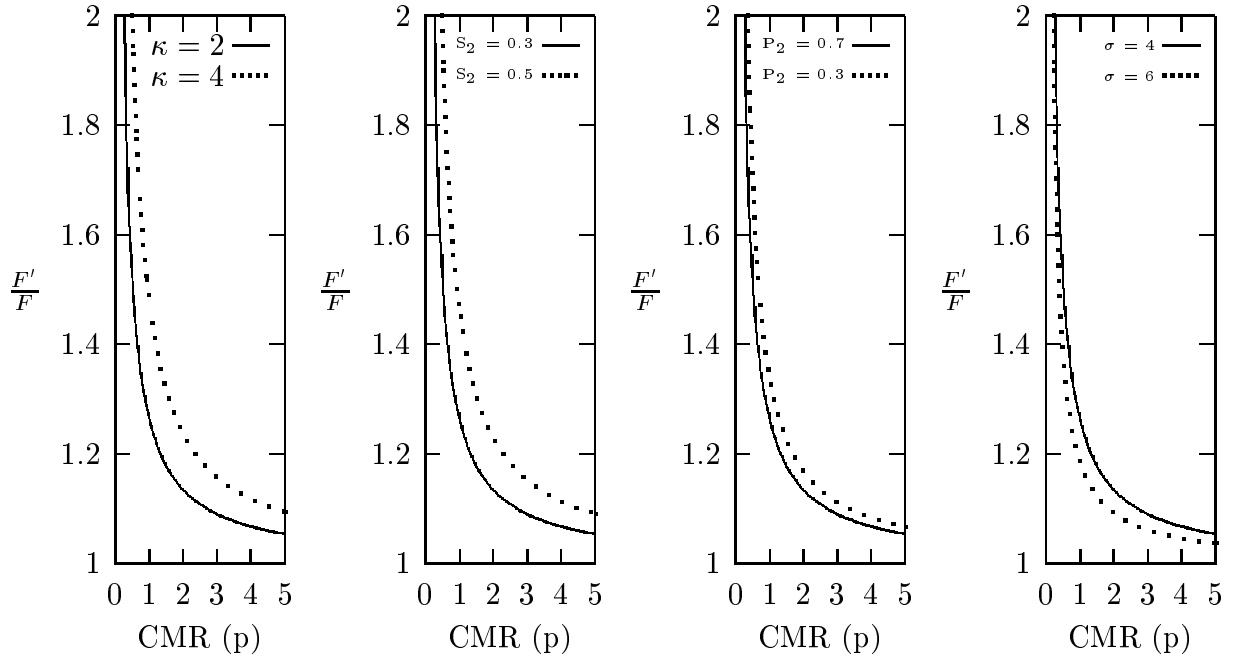

FIG. 7: *Variation in relative LOCATE cost as a function of κ, S_2 , P_2 and σ.*

involves to and fro communication between VLRs in terms of registration, de-registration and acknowledgement. Thus, $S_1 = \sigma_1 T_1$ and $S_2 = \sigma_2 T_2$. Thus,

$$
\begin{aligned}
\frac{F'}{F} &= 1 + \left(\frac{1}{p}\right)\left[P_2\left(\frac{S_1}{\sigma_1} + \frac{S_2}{\sigma_2}\right) + P_1\left(\frac{2S_1}{\sigma_1} + \frac{S_2}{\sigma_2}\right)\right] \\
&= 1 + \left(\frac{S_2}{p}\right)\left[P_2\left(\frac{\kappa}{\sigma_1} + \frac{1}{\sigma_2}\right) + P_1\left(\frac{2\kappa}{\sigma_1} + \frac{1}{\sigma_2}\right)\right]
\end{aligned}
$$

From the algorithm, it is evident that the number of communications during pointer set up is same in level-1 and level-2, hence $\sigma_1 = \sigma_2$ (where $\sigma_1, \sigma_2 \gg 1$). We now write

$$
\begin{aligned}
\frac{F'}{F} &= 1 + \left(\frac{S_2}{\sigma p}\right)[P_2(\kappa + 1) + P_1(2\kappa + 1)] \\
&= 1 + \left(\frac{S_2}{\sigma p}\right)[1 + 2\kappa - \kappa P_2] \tag{20}
\end{aligned}
$$

Eqn(20) shows that the cost in locating an user's position depends on the parameters S_2, κ, P_2 and σ. The graphs of fig 7 explicitly exhibits the dependence of relative locate cost (F'/F) on these parameters. The variations are self explanatory. However, the important point to be noted from fig 7 is the strong influence of κ (in turn S_1) and S_2 have on F'/F.

C. Total Cost in Location Tracking and Location Updating

The total cost of operation would be sum of cost incurred in location updating and tracking,

$$
\begin{aligned}
C_F &= M' + F' \\
&= \frac{2aP_2^2 S_2}{p^2} + \frac{(bP_2 S_2 + 2\kappa P_1 S_2)}{p} - S_2 + 1 + \left(\frac{S_2}{\sigma p}\right)[1 + 2\kappa - \kappa P_2] \tag{21}
\end{aligned}
$$

The cost incurred between two calls in the basic mode of operation is given as

$$
\begin{aligned}
C_B &= M + F = \frac{x}{p} + F \\
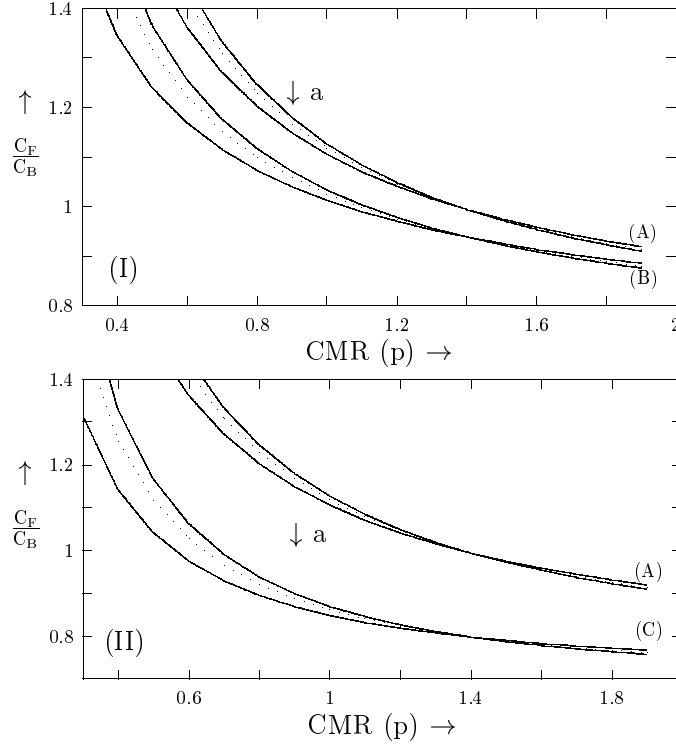&= \frac{1}{p} + 1 = \left(\frac{1 + p}{p}\right) \tag{22}
\end{aligned}
$$

FIG. 8: *Variation in total cost incurred for both location updating and location tracking. Curve (A) of both graphs have $\kappa=4$ and $\sigma=5$. While curve (B) has $\sigma=10$ and cuvre (C) has κ's value at 2. Thus, graph I compares the dependence of cost on σ and graph II compares the dependence on κ.*

For comparing the total cost of the present model w.r.t. the basic model, we find the ratio C_F/C_B using eqn(21) and eqn(22). We have

$$\frac{C_F}{C_B} = \frac{2aP_2^2 S_2}{p(1+p)} + \frac{(bP_2 S_2 + 2\kappa P_1 S_2)}{1+p} + \frac{p(1-S_2)}{1+p} + \left[\frac{S_2}{\sigma(1+p)}\right](1+2\kappa - \kappa P_2) \quad (23)$$

Figure 8 shows the variation of the total cost incurred in the location management for the proposed TLSCP scheme as compared to the basic operation mode. Figure 8(I) shows that with increase in σ, the cost of location management decreases. This is a direct result of decrease in location tracking cost ($T = S/\sigma$, see fig 6). However, as seen from fig 8(II), the cost of location management depends more strongly on κ's value, where a lower κ implies

that the cost of location updating (setting of level-1 pointers) decreases. Also notice the larger section of curves lieing below ($C_F/C_B=$) 1 on decreasing κ. This region ($C_F/C_B \leq 1$) indicates region of operation where TLSCP scheme works out to be cheaper than the basic operation scheme. Thus, even for an increased mobility (low p), the cost of operation in TLSCP scheme can be made low by decreasing the value of σ and κ.
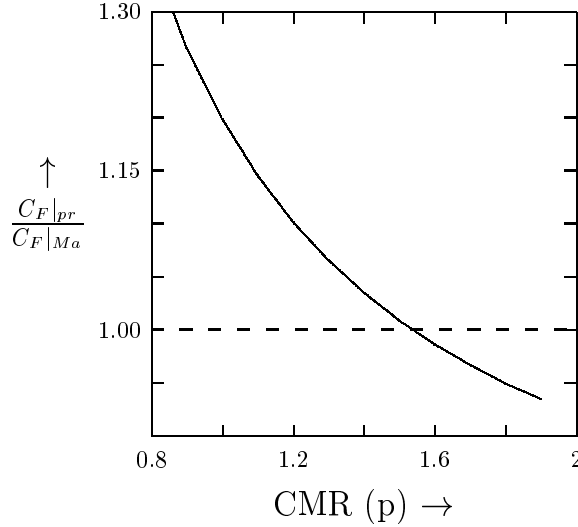

FIG. 9: Performance analysis of TLSCP strategy w.r.t. Ma and Fang's [15] strategy.

V. DISCUSSION

The analysis of the TLSCP strategy shows that despite the increase of localized signal traffic generated in a MA, the cost involved in locating a user is low. This effectively brings down the cost of operation for users with low call to mobility ratio. Efficient programming to bring down the cost in setting up level-1 pointers (making κ low) would enable the operator to expand the limit of "the low call to mobility ratio". Profiling a user and efficiently switching from TLSCP strategy to TLPF (Two Level Pointer Forwarding [15]) strategy would bring down the cost of operation significantly. Figure 9 compares the costing of the two strategies. This in principle should be easy due to the broad similarity in the two strategies.

VI.   CONCLUSION

The present article proposes a Two level single chain pointer forwarding strategy for location management. When a mobile user moves from one RA to another, it is accompanied by a pointer formation between a local anchor (which is an RA the user occupied when he last received a call) and the new RA in which the user is located. An increase in cost of MOVE action (various signals exchanged between RA's and computer information updating) drastically reduces the cost involved in tracing (Locating) an user to transfer a call. If the cost incurred in forming a *level-2* pointer, i.e. S_2 can be reduced by minimizing signal transfers required to update computer information, the total cost for location updating and location tracking (C_F) would be reduced. This would bring down the operating cost of the service provider. In the present model since a MA can manage larger RA's in it, increasing number of RA's under a MA decreases the probability of user crossing over MA's. This again strongly contributes to the decrease in operating cost. The present strategy (TLSCP) out performs the basic strategy. However, it only betters Ma and Fang (TLPFS)[15] strategy for low mobility. The model fails in decreasing cost for a user with large mobility. It would be interesting to investigate an algorithm in future works, that switches from TLSCP model to TLPFS as an increase in user mobility is detected.

APPENDIX

Based on the assumption that the residency time of a user in a RA follows Gamma Distribution, Ma and Fang[15] derived an expression for $\alpha(i)$, given as

$$\alpha(i) = \frac{[g^{i-1}(1-g)^2]}{p} = Ag^i \tag{24}$$

'g' is the Laplace transform of the Gamma Distribution function. The constant 'A' and the nature of 'g' can be evaluated by subjecting it to the conditions given by eq(12), i.e.

$$\int_0^\infty \alpha(i)di = 1$$

using eqn(24) in this relation, we have

$$A \int_0^\infty g^i di = -\frac{A}{[log(g)]} = 1$$

This gives

$$A = -log(g) \tag{25}$$

(this is subjected to the condition g < 1). From eqn(13) we get

$$\int_0^\infty i\alpha(i)di = \frac{1}{p}$$
$$-log(g) \int_0^\infty ig^i di = \frac{1}{p}$$
$$-\frac{1}{[log(g)]} = \frac{1}{p}$$

This gives the functional form of 'g' as *exp(-p)* and in turn

$$\alpha(i) = pe^{-pi} \tag{26}$$

where p is the CMR.

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